Fermi National Accelerator Laboratory

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Modeling a Ferrite-Tuned RF Cavity

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Abstract

A Fermilab Booster RF cavity has been modeled using computer codes collectively known as MAFIA. Because of the complicated geometry of these cavities over 87000 mesh points were used to obtain an accurate simulation. The results of the numerical simulations were then compared with experimentally-measured resonant frequencies. The reasonable agreement found between the calculations and the experimental data indicates that the URMEL-3D part of the MAFIA codes can be used to describe and design RF cavities with a permeability as high as $\mu = 12.0$ and with a geometry as complicated as that exhibited by the Fermilab Booster cavities.

1 Introduction

The proton beam in the Fermilab Booster Synchrotron is accelerated in $33.0ms$ from $200MeV$ to $8GeV$ using 15 ferrite-tuned cavities. In this time interval RF changes from $30.10MHz$ to $52.813MHz$.

Figure 1. is a cut-away drawing of a booster cavity with a power amplifier and three ferrite tuners mounted on it.

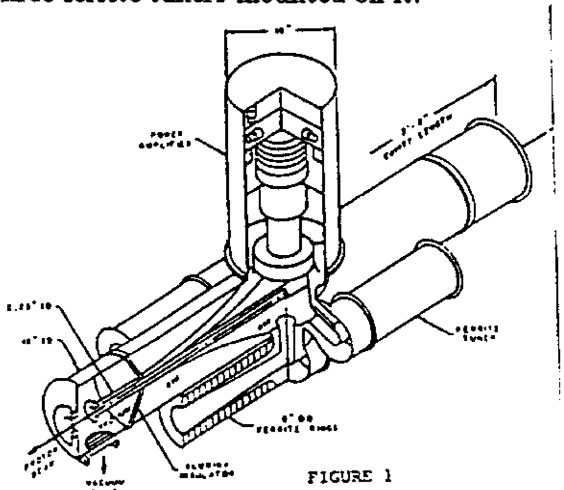

FIGURE 1

The cavity contains a drift tube whose electrical length is 140 degrees and an accelerating gap at each end. The drift tube is a tapered copper structure with a 2-1/4" i.d. beam pipe in the center. An alumina insulator, with permittivity $\epsilon = 9$, near each end of the drift tube provides a vacuum-tight rf window. Only the beam pipe inside the drift tube and the accelerator gaps at the ends of the cavity are under vacuum. The central part of the cavity and the tuners are under atmospheric pressure.

Three tuners are attached to each cavity. The tuners are coaxial transmission line structures with shorted ends. The center conductor of each tuner is connected to the center of the drift tube in the accelerating cavity, and the tuners are part of the resonating structure. There are 28 toroidal ferrite cores, with permeability $\mu = 7.5$, mounted in the rf field between the inner and outer conductor of the tuner. A ten-turn bias winding passes through the center conductor of each tuner and links the ferrite cores. The reactance of the tuners and, consequently, the resonant frequency of the cavity structure is controlled by varying the current through the bias winding. The current in the tuners of each cavity is software controlled and follows the frequency change necessary to accelerate beam in the Booster. Differences between an individual cavity and the rf drive frequency is corrected by a feedback loop on each cavity which minimizes the phase difference between the rf drive and the fields in the cavity [1].

2 Simulation

MAFIA is the name given to a set of codes intended for use in the design of three-dimensional RF-structures [2]. MAFIA solves Maxwell Equations using Finite Integration Algorithm and calculates the resonant frequencies of RF cavities. Because of the large physical dimensions (2.4 meters long, 1.2 meters width with tuners and 1.4 meters high with tuner and power amplifier and only two planes of symmetry) over 87,000 mesh points were needed to simulate the Fermilab Booster Cavity.

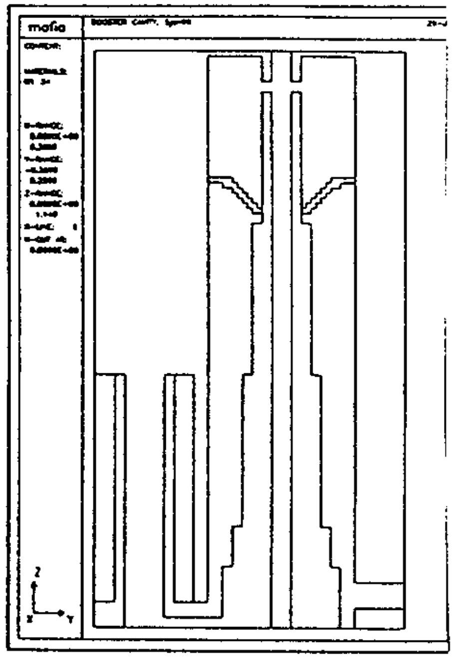

Figure 2

Figure 2 displays the geometrical cross sections used in the calculations and

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3
(1.,0.) (1.0,0.) 0., 0                          Ferrite
4                                               Dielectric
(0.,0.) (1.,0.) 0., 0
 SUMMARY OF MESH CHARACTERISTICS
 -------------------------------

 NUMBER OF MESH LINES IN X           =     37
 NUMBER OF MESH LINES IN Y           =     54
 NUMBER OF MESH LINES IN Z           =     44
 TOTAL NUMBER OF MESH POINTS         =  87912

 BOUNDARY CONDITIONS 1  2  1  2  1  1  1

 NUMBER OF MODES WANTED                - NMODE =        40
 NUMBER OF MODES TO BE SAVED           - MAXSAV=         6
 UPPER FREGENCY-LIMIT FOR ITERATION    - FUP   =  1.300E+03 MHZ
 PREC. FACTOR FOR FIRST ITERATION      - PFAC0 =  1.000E+00
 PASSAGES FOR FIRST ITERATION          - NPASS0=         2
 PREC. FACTOR FOR SEPARATION-ITERAT.   - PFAC1 =  1.000E+00
 PREC. FACTOR FOR CLEANING             - PFAC2 =  1.000E+00
 PASSAGES FOR CLEANING                 - NPASS2=         1
 PRECISION-LIMIT FOR ACCEPTING MODE    - DVLIM =  1.000E-01
 RANDOM START-PARAMETER USED           - NRNDM =         1
1SUMMARY OF ALL MODES FOUND -----------------------------
```

Table 1

Table 1 lists the MAFIA input parameters. Figure 3 displays the resonant frequencies calculated by MAFIA calculations up to $300 MHz$ as function of ferrite μ.

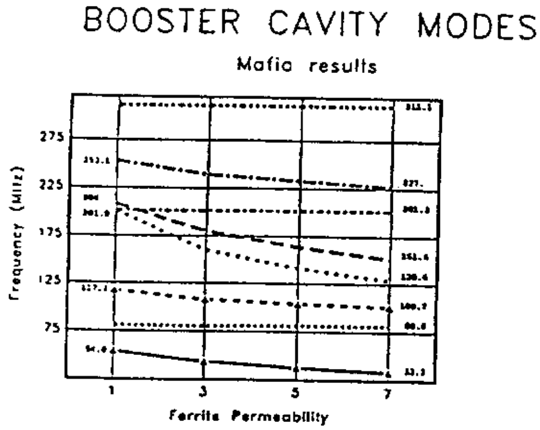

Figure 3

3 Measurement

The measurement of the frequency response of the cavity was done using two antenna-type probes. The signal from the RF signal generator was applied at one accelerating gap through this probe. The receiving antenna was mounted at the second accelerating gap and connected to a spectrum analyzer. As the RF signal was swept from 10 to 300 MHz, the resonant frequencies of the cavity appeared as peaks in the amplitude of the signals received by the second probe and sent to the spectrum analyzer. During the RF sweep, the ferrite bias current was kept constant. The resonant frequencies as function of bias current arepresented in Table 2.

I	f_0	f_1	f_2	f_3	f_4	f_5
35	30.0	75.5	80.5	102.2	128.1	187.5
61.5	31.2	75.5	80.5	107.1	136.1	187.5
110.7	34.1	75.5	80.5	110.9	147.7	187.5
185.0	37.0	75.5	80.5	118.7	160.8	186.0
457.5	42.8	75.5	80.5	138.1	213.8	187.5
847.5	47.4	75.5	80.5	150.6	230.4	187.5
2032.0	52.3	75.5	80.5	163.0	249.0	187.5

Table 2. The current I is in Amps and frequencies f are in MHz. The f_0 is fundamental mode.

4 Conclusion

A direct comparison between measurements and calculations cannot be made because the characteristic frequencies were measured as a function of bias current instead of μ. However, the the agreement of calculations with data in the case of non-tunable frequencies and consistency of the curves in Figure 3, indicate that MAFIA codes provide a reasonable description and can be used as design tool for RF cavities.

5 References

[1] Design Report, National Accelerator Laboratory (1968)

[2] T. Barts, M. J. Browman, R. Cooper, C. T. Mottershead, G. Rodenz, S. G. Wipf, R. Klatt, F. Krawczyk, W. R. Novender, C. Palm, T. Weiland, B. Steffen, "MAFIA - A Three- Dimensional Electromagnetic CAD System for Magnets, RF Structures and Transient Wake-Field Calculations", Proc. 1986 Linac Conf., Stanford, California